Blackwell Science

Chapter 4

Large-scale Characteristics and Variability of the Global Sea Ice Cover

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4.1 Introduction

At high latitudes, the global oceans are covered by vast blankets of sea ice which range in extent at any one time between 17.5×10^6 to $28.5 \times 10^6\,km^2$. This corresponds to a significant fraction (3–6%) of the total surface area of the earth. In the Arctic region, the ice cover doubles its size from summer to winter, while in the Antarctic the corresponding value is five-fold (Zwally et al., 1983a; Parkinson et al., 1987; Gloersen et al., 1992). The sea ice cover is thus one of the most expansive and most seasonal geophysical parameters on the earth's surface, second only to the more variable and less predictable snow cover. The presence or absence of sea ice affects the atmosphere and the ocean, and therefore the climate, in many ways. For example, as an insulating material, it limits the flow of heat between the ocean and atmosphere. On account of its high albedo, a high fraction of solar radiation is kept from being directly absorbed by the surface and is instead reflected back to the atmosphere. It is because of such feedback effects between surface and atmosphere that climate change signals are expected to be amplified in polar regions (Budyko, 1966).

The impact of the sea ice cover on the ocean is equally significant. For example, the process of growth and decay of sea ice causes vertical and/or horizontal redistribution of salt in the ocean. During ice formation, brine rejection causes enhanced salinity of the underlying ocean and this process can initiate vertical convection and/or the formation of bottom water. Conversely, during ice retreat, low salinity melt water is introduced and causes the upper layer of the ocean to be stratified and vertically stable. The latter is conducive for phytoplankton growth and thereby increases the productivity of the region (Smith et al., 1988; Comiso et al., 1992; Arrigo, Chapter 5). Large polynyas within the pack and ice features, such as the Odden ice tongue, have been discovered and associated with deep ocean convection (Gordon & Comiso, 1988; Comiso et al., 2001). Latent heat polynyas, which are usually near coastal regions and caused primarily by strong katabatic winds, have also been observed (Zwally et al., 1985; Comiso & Gordon, 1998; Markus et al., 1998; Massom et al., 1999), and have been postulated as the key source of the high salinity bottom water that is involved in global thermohaline circulation.

In-depth studies of the variability of sea ice cover is thus important, especially in light of recent reports of the declining extent (Johannessen et al., 1995; Cavalieri et al., 1997; Jacobs & Comiso, 1997) and thickness (Rothrock et al., 1999; Wadhams & Davis, 2000) of the Arctic ice cover. Large-scale variability in the sea ice cover has been quantified previously using satellite passive microwave data (Zwally et al., 1983a; Parkinson et al., 1987; Gloersen et al., 1992; Bjørgo et al., 1997; Stammerjohn & Smith, 1997; Parkinson et al., 1999; Zwally et al., 2002). Large changes in the ice cover were also reported in the 1990s, especially in the Arctic (Haas, Chapter 3), but more detailed studies are needed to better understand the climate system in the region.

4.6 Summary

More than two decades of satellite data are now available for detailed study of the large-scale characteristics and changing state of the sea ice cover in both northern and southern hemispheres. Satellite passive microwave data provide, day and night, almost continuous observation of the global sea ice cover thereby enabling quantitative variability studies at various time and spatial scales. Despite relatively coarse sensor resolution, spatial detail is provided through the use of sea ice concentrations which are derived using an algorithm that determines the fraction of ice and open water within each satellite footprint. Satellite infrared data provide day/night coverage as well but are limited to only cloud-free conditions. However, the sampling statistics for this data are high and the results provide the only spatially detailed distributions of surface temperatures in the polar regions that have good enough accuracies to detect interannual changes in all regions. High-resolution satellite data are also shown to be useful in studies of small-scale characteristics and seasonal changes in the physical properties of the ice cover.

Large seasonal fluctuations in the ice extent and area are apparent, with those of the southern hemisphere having larger amplitudes but a less symmetrical seasonal distribution than those of the northern hemisphere. The large-scale interannual variability of the ice cover has been evaluated globally as well as regionally, and in the northern hemisphere, the yearly anomaly maps show large interannual variability and a predominance of positive values in the 1980s and negative values in the 1990s. Yearly anomaly maps of surface temperatures show similar anomalies but with opposite sign indicating a strong link between the ice cover and surface temperatures. In the Antarctic, large year-to-year anomalies in the ice cover are also observed but they follow a pattern of alternating positive and negative anomalies around the continent. Similar patterns are observed in the yearly surface ice temperature anomaly maps that, together with the ice data, show consistency with a propagating ACW that circles the oceans around Antarctica.

Globally, the sea ice cover is shown to be on a decline in the northern hemisphere while only minimal changes are observed in the southern hemisphere. Regression analysis shows that the ice extent and ice area in the northern hemisphere are declining at the rate of $-2.0 \pm 0.3\%$ and $-3.1 \pm 0.3\%$ per decade, respectively, but there are regions like the Bering Sea with positive trends. The rate of decline in extent is strongest in the summer at $-4.1 \pm 0.9\%$ per decade and weakest in the winter at $-0.8 \pm 0.5\%$ per decade.

The most remarkable result, however, is the rapidly declining state of the Arctic perennial sea ice cover, the rate of decline being -6.4 ± 2.1 and $-8.5 \pm 2.0\%$ per decade for ice extent and ice area, respectively. Such results are important in that the perennial ice cover consists mainly of the thick multi-year ice cover that basically controls the thickness distribution and limits the retreat of the ice during the summer. A sustained decline at this rate could mean the disappearance of the perennial ice in this century and profound changes in the Arctic Ocean and its environment. It should be noted as well that in consolidated ice regions, the average temperature during the summer has been increasing at about 1.2 ± 0.6 K per decade indicating a longer melt season and therefore decreasing ice volume (Hakkinen & Mellor, 1990).

In the southern hemisphere, the sea ice cover is highly variable but the predictability depends on how well the processes in the region are understood. Alternating negative and positive anomalies occur around the periphery of the ice-covered region, and year-to-year changes confirm the presence of an ACW that propagates in a clockwise direction around the continent. Both ice and temperature anomalies are highly correlated indicating that these two parameters are indeed closely linked with each other. The year-to-year changes in the anomaly patterns are, however, not always in line with that expected from the ACW, indicating that the ice cover is not so predictable on a year-by-year basis.